# Humidity & Air conditioning

Md Khairul Islam (Ph.D)
Applied Chemistry & Chemical Engineering
University of Rajshahi

# What is Humidity?

Humidity, H is the mass of vapor carried by a unit mass of vapor-free gas. So defined, humidity depends only on the partial pressure of the vapor in the mixture when the total pressure is fixed. If the partial pressure of the vapor is $p_A$ atm, the molal ratio of vapor to gas at 1 atm is $p_A/(1 - p_A)$. The humidity is therefore

$$H = \frac{M_A p_A}{M_B(1 - p_A)}$$

where $M_A$ and $M_B$ are the molecular weights of components A and B, respectively.

# Related terminology

Saturated gas is gas in which the vapor is in equilibrium with the liquid at the gas temperature. The partial pressure of vapor in saturated gas equals the vapor pressure of the liquid at the gas temperature. If $H_S$ is the saturation humidity and $P_A$ the vapor pressure of the liquid,

$$H_S = \frac{M_A P'_A}{M_B(1 - P'_A)}$$

# Related terminology

Relative humidity, $H_R$ is defined as the ratio of the partial pressure of the vapor to the vapor pressure of the liquid at the gas temperature. It is usually expressed on a percentage basis, so 100 percent humidity means saturated gas and 0 percent humidity means vapor-free gas. By definition,

$$H_R = 100 \times \frac{p_A}{P'_A}$$

Percentage humidity, $H_A$ is the ratio of the actual humidity H to the saturation humidity $H_S$ at the gas temperature, also on a percentage basis, or

$$H_A = 100 \times \frac{H}{H_s} = 100 \times \frac{p_A/(1-p_A)}{P'_A/(1-P'_A)} = H_R \times \frac{1-P'_A}{1-p_A}$$

At all humidities other than 0 or 100 percent, the percentage humidity is less than the relative humidity.

# Related terminology

Humid heat, $c_s$ is the heat energy necessary to increase the temperature of 1 g or 1 lb of gas plus whatever vapor it may contain by 1°C or 1°F. Thus,

$$c_s = c_{pB} + c_{pA}H$$

Where, $c_{pB}$ and $c_{pA}$ are the specific heats of gas and vapor, respectively.

# Related terminology

Humid volume, $v_H$ is the total volume of a unit mass of vapor-free gas plus whatever vapor it may contain at 1 atm and the gas temperature. From the gas laws, $v_H$ in fps units is related to humidity and temperatures by the equation,

$$v_H = \frac{359T}{492}\left(\frac{1}{M_B} + \frac{\mathcal{H}}{M_A}\right)$$

where, T is the absolute temperature in degrees Rankine. In SI unit the equation is,

$$v_H = \frac{0.0224T}{273}\left(\frac{1}{M_B} + \frac{\mathcal{H}}{M_A}\right)$$

$v_H$ is in cubic meters per gram and T is in Kelvins. For vapor-free gas, H = 0, and $v_H$ is the specific volume of the fixed gas. For saturated gas, H = $H_S$ and $v_H$ becomes the saturated volume.

# Related terminology

Dew point, is the temperature to which a vapor-gas mixture must be cooled (at constant humidity) to become saturated. The dew point of a saturated gas phase equals the gas temperature.

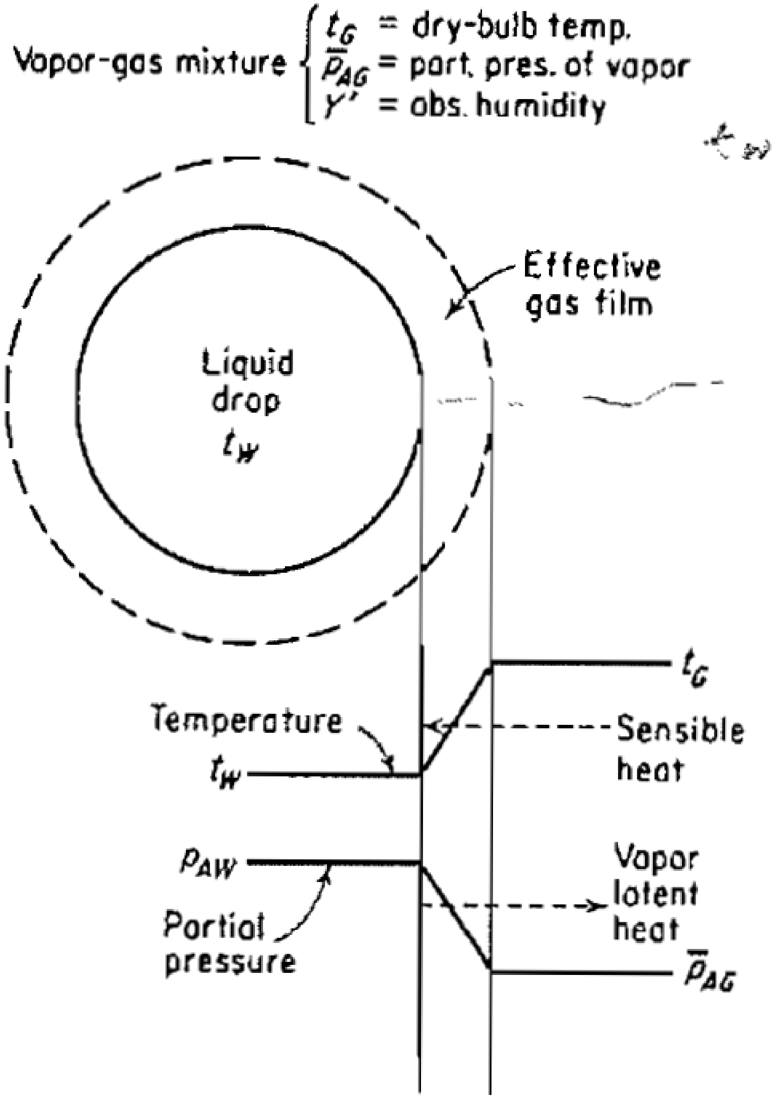
Total enthalpy, $H_y$ is the enthalpy of a unit mass of gas plus whatever vapor it may contain. Let the temperature of the gas be T and the humidity S. The total enthalpy is the sum of three items; the sensible heat of the vapor, the latent heat of the liquid at $T_0$, and the sensible heat of the vapor-free gas. Then

$$H_y = c_{pB}(T - T_0) + \mathscr{H}\lambda_0 + c_{pA}\mathscr{H}(T - T_0)$$

where $\lambda_0$ is the latent heat of the liquid at $T_0$. This equation becomes

$$H_y = c_s(T - T_0) + \mathscr{H}\lambda_0$$

# Wet bulb temperature



# Wet bulb temperature

The wet-bulb temperature is the steady-state, non-equilibrium temperature reached by a small mass of liquid immersed under adiabatic conditions in a continuous stream of gas. The mass of the liquid is so small in comparison with the gas phase that there is only a negligible change in the properties of the gas. A thermometer is covered by a wick, which is saturated with pure liquid and immersed in a stream of gas having a definite temperature T and humidity X. Since the gas is not saturated, liquid evaporates, and because the process is adiabatic, the latent heat is supplied at first by cooling the liquid. As the temperature of the liquid decreases below that of the gas, sensible heat is transferred to the liquid. Ultimately, a steady-state is reached at such a liquid temperature that the heat needed to evaporate the liquid and heat the vapor to gas temperature is exactly balanced by the sensible heat flowing from the gas to the liquid. It is this steady-state temperature, called the wet-bulb temperature.

# Wet bulb theory

At wet bulb temperature, sensible heat transfer from air to water,

$$q = \lambda_A A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, A is the rate of vaporization, lb water per hour and $\lambda_A$ is the latent heat at wet bulb temperature, Btu/lb

The transfer of sensible heat is equal to the product of three factors i.e., the coefficient of heat transfer, the area of the surface through which the heat is flowing, and the temperature drop. In terms heat transfer coefficient, sensible heat transfer-

$$q = (h_B + h_R) \; (S) \; (t_B - t_w) \quad \ldots\ldots\ldots\ldots\ldots(2)$$

Where, $h_B$ represent the heat-transfer coefficient from the air to the wetted surface by convection, $h_R$ the heat-transfer co-efficient corresponding to radiation from the surroundings, S the surface area of the drop, $t_B$ temperature of the bulk air and $t_w$ temperature of interface of A and B

# Wet bulb theory

The rate of mass transfer of water from the interface to the bulk of the gas mixture may be represented by the equation-

$$N_A = k_B S(p_w - p_B) \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Where, $k_B$ is the mass transfer coefficient

Since the rate is desired in pounds per hour, rather than pound moles per hour

$$18N_A = 18\, k_B S(p_w - p_B) \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

For the steady state condition,

$$A = 18\, k_B S(p_w - p_B) \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Putting the value of q and A in equation (1)

$$(h_B + h_R)\ (S)\ (t_B - t_w) = 18\, \lambda_A k_B S(p_w - p_B)$$

$$(p_w - p_B) = [(h_B + h_R)/18\, \lambda_A k_B\,]\ (t_B - t_w) \quad \ldots\ldots\ldots(6)$$

# Wet bulb theory

Since $h_R$ is too small campared to $h_B$, it can be ignored

$$(p_w - p_B) = (h_B/18\ \lambda_A\ k_B)\ (t_B - t_w)\ \ldots\ldots\ldots\ldots.(7)$$

We know, Humidity $H = 18p/\ 29(1-p) \approx 18p/29$

Partial pressure of vapor at wet & dry bulb temperatures

$$p_w = 29H_A/18 \quad \text{and} \quad p_B = 29H_B/18$$

Substituing the value of $p_A$ and $p_B$ in equation (7)

$$(H_w - H_B) = (h_B/29\ \lambda_A\ k_B)\ (t_B - t_w)$$

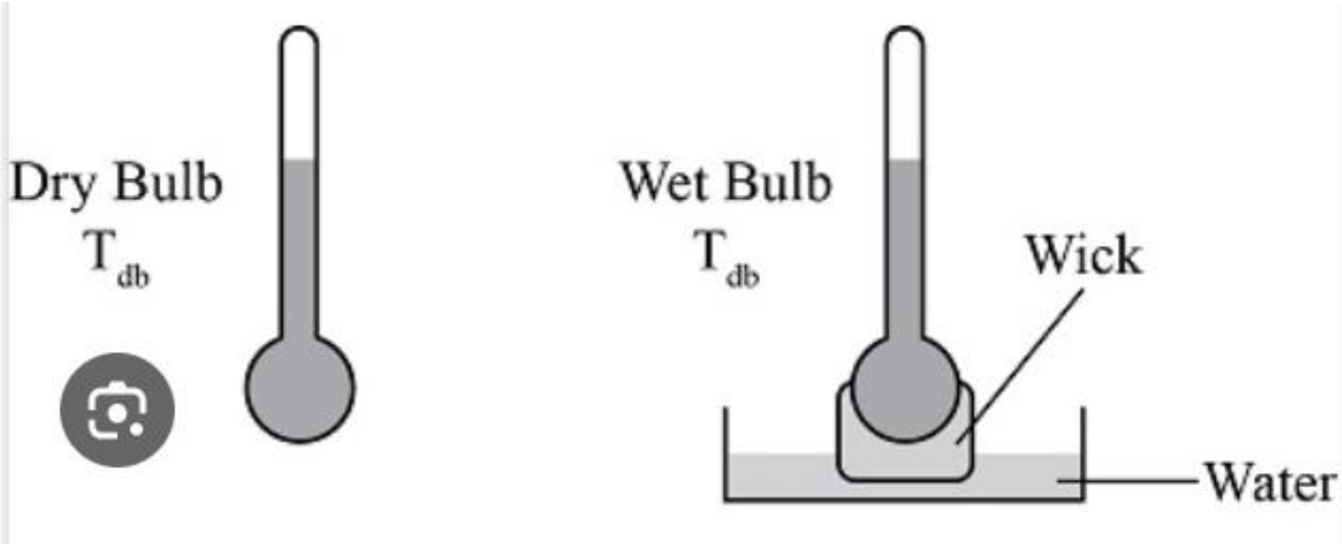
$$(H_w - H_B) = (h_B/k_B M_B)(1/\ \lambda_A\ )\ (t_B - t_w)\ \ldots\ldots\ldots..(8)****$$

The equation (8) is developed for 1 atm pressure, so a value for P should be included

$$(H_w - H_B) = (h_B/k_B M_B P)(1/\ \lambda_A\ )\ (t_B - t_w)\ \ldots\ldots\ldots\ldots.(9)$$

# Wet bulb temperature

Wet bulb temperature is measured using a device called a wet-bulb thermometer, which consists of a thermometer with its bulb covered by a moistened cloth (often muslin). This cloth is kept wet by wicking action from a reservoir of water. The temperature registered by the thermometer is lower than the dry bulb temperature (ambient temperature) due to the cooling effect of evaporation.



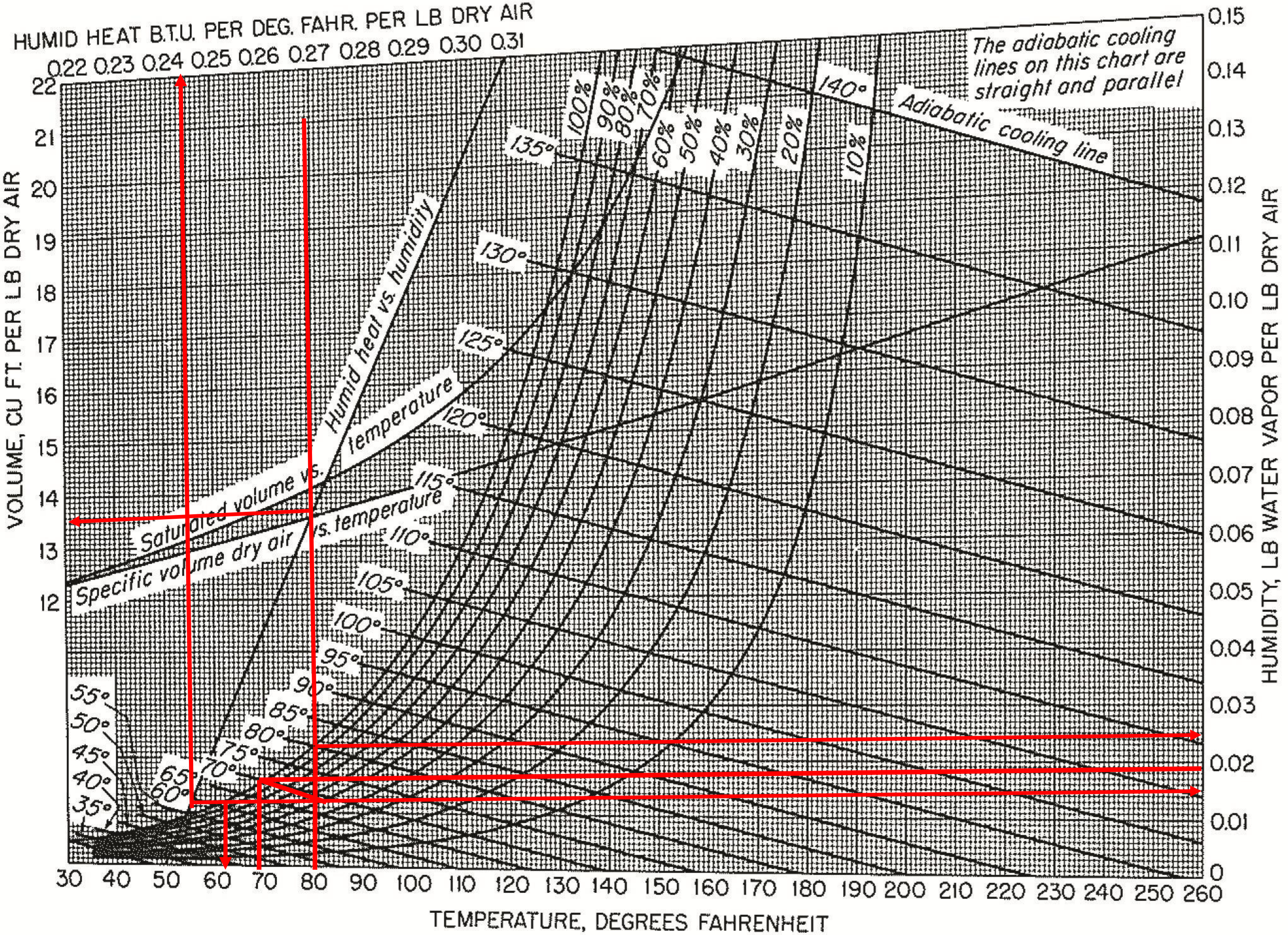
# Wet bulb temperature

To measure the wet-bulb temperature with precision, three precautions are necessary:

(1) the wick must be completely wet so no dry areas of the wick are in contact with the gas;

(2) the velocity of the gas should be large enough to ensure that the rate of heat flow by radiation from warmer surroundings to the bulb is negligible in comparison with the rate of sensible heat flow by conduction and convection from the gas to the bulb;

(3) if makeup liquid is supplied to the bulb, it should be at the wet-bulb temperature. When these precautions are taken, the wet-bulb temperature is independent of gas velocity over a wide range of flow rates.

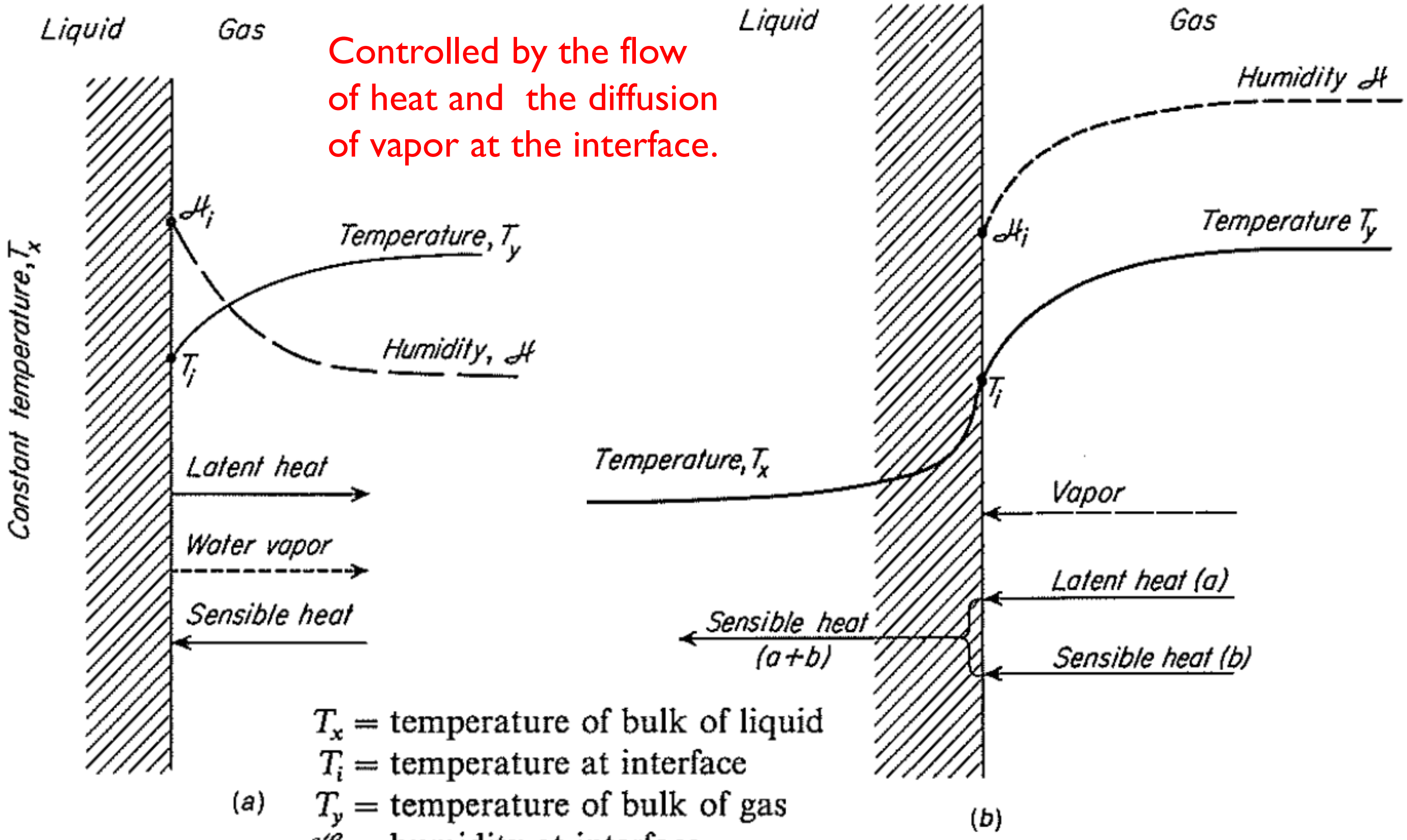

HUMID HEAT B.T.U. PER DEG. FAHR. PER LB DRY AIR
0.22 0.23 0.24 0.25 0.26 0.27 0.28 0.29 0.30 0.31
VOLUME, CU FT. PER LB DRY AIR
22
21
20
19
18
17
16
15
14
13
12
HUMIDITY, LB WATER VAPOR PER LB DRY AIR
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
TEMPERATURE, DEGREES FAHRENHEIT
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260
The adiabatic cooling lines on this chart are straight and parallel
Adiabatic cooling line
Humid heat vs. humidity
Saturated volume vs. temperature
Specific volume dry air vs. temperature
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
140°
135°
130°
125°
120°
115°
110°
105°
100°
95°
90°
85°
80°
75°
70°
65°
60°
55°
50°
45°
40°
35°

# MEASUREMENT OF HUMIDITY

- **Dew-point methods:** A cooled polished disk is inserted into gas of unknown humidity and the temperature of the disk gradually lowered, the dew point is noted at which mist condenses on the polished surface. A check on the reading is obtained by slowly increasing the disk temperature and noting the temperature at which the mist just disappears. From the average of the temperatures of mist formation and disappearance, the humidity can be read from a humidity chart.
- **Psychometric methods:** Use wet-bulb and dry-bulb temperatures. From these readings the humidity is found by locating the psychometric line intersecting the saturation line at the observed wet-bulb temperature and following the psychometric line to its intersection with the ordinate of the observed dry-bulb temperature.
- **Direct methods:** The vapor content of a gas can be determined by direct analysis, in which a known volume of gas is drawn through an appropriate analytical device.

# Mechanism of interaction of gas and liquid

Controlled by the flow of heat and the diffusion of vapor at the interface.

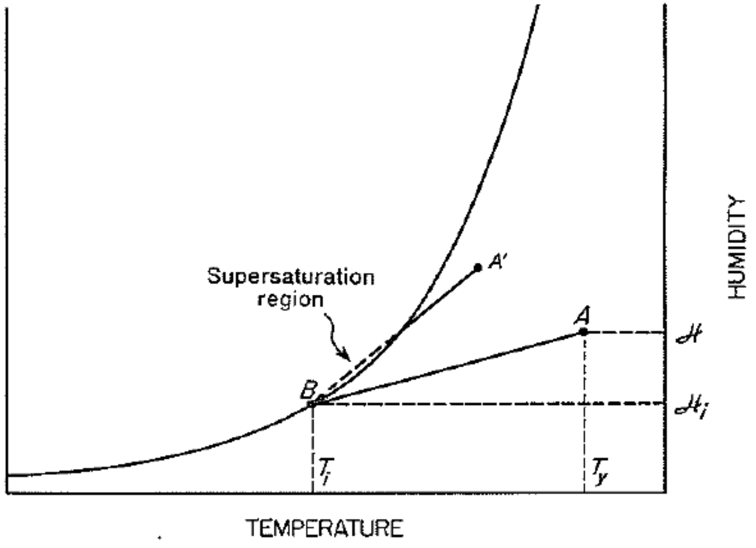


$T_x$ = temperature of bulk of liquid
$T_i$ = temperature at interface
$T_y$ = temperature of bulk of gas
$\mathscr{H}_i$ = humidity at interface
$\mathscr{H}$ = humidity of bulk of gas

Conditions in (a) humidifier and (b) dehumidifier

# Mechanism of interaction of gas and liquid

The rate of heat transfer (temperature change) outruns the mass-transfer rate (humidity change) so that the gas becomes supersaturated. If the gas contains dust or other particles that can serve as nuclei for droplet formation, the super saturation may be relieved by condensation on these particles instead of on the bulk liquid surface. This can lead to a persistent, troublesome fog.



Dehumidification by cold liquid

Fog formation may be avoided by making sure that the initial gas temperature is well above the equilibrium value, as at point A, or by adding heat to the gas during the humidification process.